

DEFECT CHARACTERIZATION BY SPATIAL DISTRIBUTION  
OF ULTRASONIC SCATTERED ENERGY\*

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The ultrasonic pulse echo technique is a highly sensitive nondestructive method for detecting small defects within the bulk of a structure. The technique is capable of reliably finding small volumetric defects when the defect size is approximately 0.030 inches in diameter and the specimen thicknesses are not too great. If the distance between the transducer and the defect is large, greater than 2 near field distances, the minimum value of volumetric flaw sizes that can be reliably detected rises considerably. For 6-8 inch thick plates, it is not too surprising to occasionally miss volumetric defects such as slag inclusions of considerable length.

If the defects are planar in nature, and tightly closed such as fatigue cracks, the sensitivity of the ultrasonic technique is such that flaws smaller than 0.10 inches long by 0.050 deep cannot be detected to high degree of probability. Table I lists some of the currently available reliability data on flaw detection of fatigue cracks by production UT methods.<sup>1-6</sup>

There are several reasons for this drop in sensitivity for tight cracks. These can be summarized as follows:

1. The tightness of the crack does not reflect as much ultrasonic energy as a volumetric defect of the same apparent projected area.<sup>7</sup>
2. Adjacent portions of the crack faces are in contact with each other, transmitting portions of the impinging ultrasonic energy.<sup>8</sup>
3. The surface roughness of the crack, particularly the fatigue striations and angularity changes due to crossing metallurgical boundaries, disperse some of the initial energy.<sup>9</sup>
4. Plastic deformation associated with the stress field surrounding the crack may diffuse the initial energy.
5. The gross orientation of the crack plane may not be directly perpendicular to the initial pulse wave, and curvature of the crack faces may reflect a portion of the energy back to other portions of the specimen.<sup>10</sup>

The problem of determining the degree of criticality of the flaw size, shape and orientation is very difficult.<sup>11</sup> Few studies have been conducted on the measurement of the size of small defects by UT. For the case of defects whose size is considerably larger than the diameter of the transducer, several techniques are available.<sup>12,13,14</sup> These include the AVG diagrams developed by Krautkramer<sup>15</sup> and the position scanning methods developed by

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Table I.

## ULTRASONIC FATIGUE CRACK DETECTION DATA

Technique/Matl'l	Flaw Size Length & Depth inches	Prob of Detection %	Confidence Level %	Reference
Ultrasonics 2219-T87 0.2" or 0.36"	.186 x .038	90%	95%	(1)
Ultrasonics Shear Wave 2219-T87	.07 .18	90% 95%	95% (set 2) 95% (set 2)	(2)
	.07 .10	90% 95%	95% (set 3) 95% (set 3)	(2)
	.125 .33	90% 95%	95% (set 2) 95% (set 2)	(2)
	.80 .15	90% 95%	95% (set 1) 95% (set 1)	(2)
Shear Wave 7075-T6511	.25	90%		(3)
4340 V Mod.	.20	90%		(3)
Ultrasonic Surface Wave 2219-T87	.20	90%	preproof	(4)
Ultrasonic Shear	.09 .03	99% 50%		(5) (5)
5Al-2.5Sn Titanium 0.125" Thick				
Ultrasonic Shear	0.07	99%		(5)
5Al-2.5Sn Titanium	0.05	97%		(5)
0.5" Thick	0.07	50%		(5)
Ultrasonic Shear	.28	99%		(5)
2219 Al	.05	50%		(5)
0.50" Thick				
0.02" Thick	.05	99%		(5)
Delta Scan D6AC	.150	90%	induced flaws	(6)
Duplex inspection	.030-075.	90%	95%	(6)

Giacomo, Crisci and Goldspiel.<sup>16</sup> Both techniques are relatively accurate for larger defects. The Giacomo technique uses the motion of the transducer to determine the size of the defect. The transducer is moved slowly across the defect until the reflected signal reaches some lower threshold edge, passes through a maximum and diminishes as it passes beyond the crack plane. Geometric analysis of the diverging ray pattern emanating from the transducer is used to estimate the size of the flaw. In almost all cases the ultrasonic signal analysis underestimates the size of the flaw. These underestimates are attributed to 1) tightness of the flaw, 2) multiple reflections from the rough surfaces of the crack and 3) diffraction effects.<sup>16</sup>

The AVG diagram introduced in 1959,<sup>15</sup> relates the distance of the flaw from the probe (A), the amplification of the signal (V) in db and the equivalent reflector diameter (G). A reference graph is drawn for a transducer by plotting the amplitude in db from a series of flaw disc shaped reflectors as a function of the distance of the reflector disc to the transducer probe in a water bath immersion system. The ultrasonic attenuation of the water is then subtracted out and typical graphs show the reflection conditions without the immersion attenuation. The backwall echo shows that the reflection of large defects becomes nearly linear with the distance when in the far field of the transducer (approximately three near field distances). The radiation laws for small reflectors show decreases more nearly proportional to  $1/\text{distance}^2$ .

Measurements of the equivalent area of the flaw by consideration of reflected amplitude gives information about the possible minimum dimensional values and not about the actual dimension of the flaw. It is apparent that flaws of different geometric configuration can produce the same maximum reflection height, and hence appear to the ultrasonic beam to be the same equivalent area. Eccentric elliptical-crack like defects and circular flaw defects of the same area are two typical examples.

The amount of information about the revealed flaw can be substantially increased by considering two aspects of the reflected signal, namely the frequency content and the indicatrix of scattering.

Considerable information is available on the use of frequency analysis of ultrasonics as a tool for the characterization of defects.<sup>17,18</sup> In this type of analysis the frequency content of the ultrasonic pulse is examined, and found to change with shape of the defect. This technique was initially proposed by Gericke.

The use of the indicatrix or indicia as a method of determining information about the shape of the flaw was initially proposed by Gurvich and Shchukin<sup>19</sup> and further developed by Gurvich and Yermelov<sup>2</sup>. The indicia is defined as the standardized function which describes the field of the ultrasonic waves reflected by the defect to the receiver. Thus, the indicia measures the totality of reflected energy from a defect associated with the scattering of the ultrasonic waves from a transmitter, as picked up by a receiver when both transmitter and receiver are moving in a prescribed path.

A typical example of an indicia is shown in Fig. 1. Here the magnitude of reflected energy  $I_r$  is shown as a function of the position of the trans-

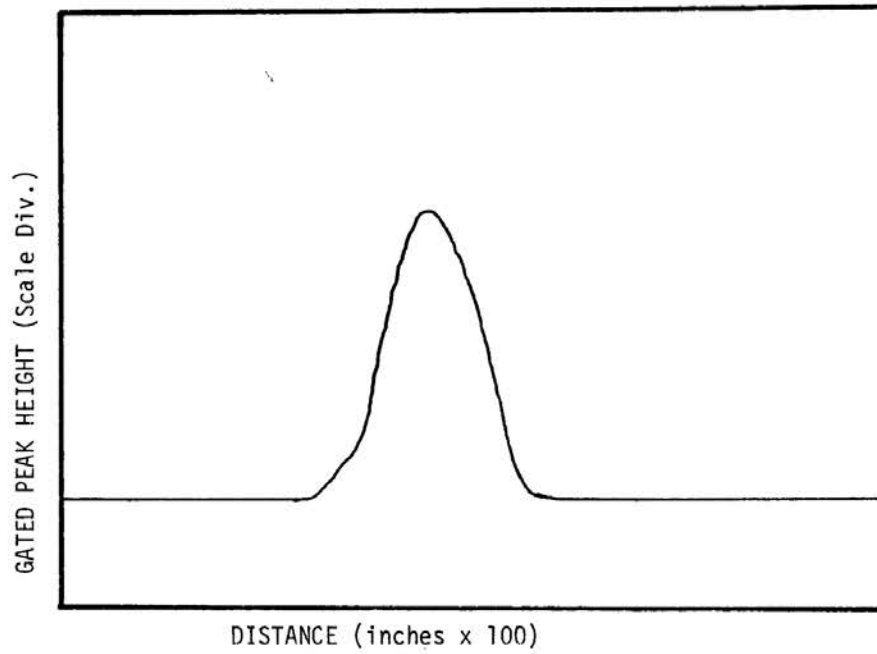


Fig. 1. Typical ultrasonic shear wave indicia of good hole (0.5 dia.)

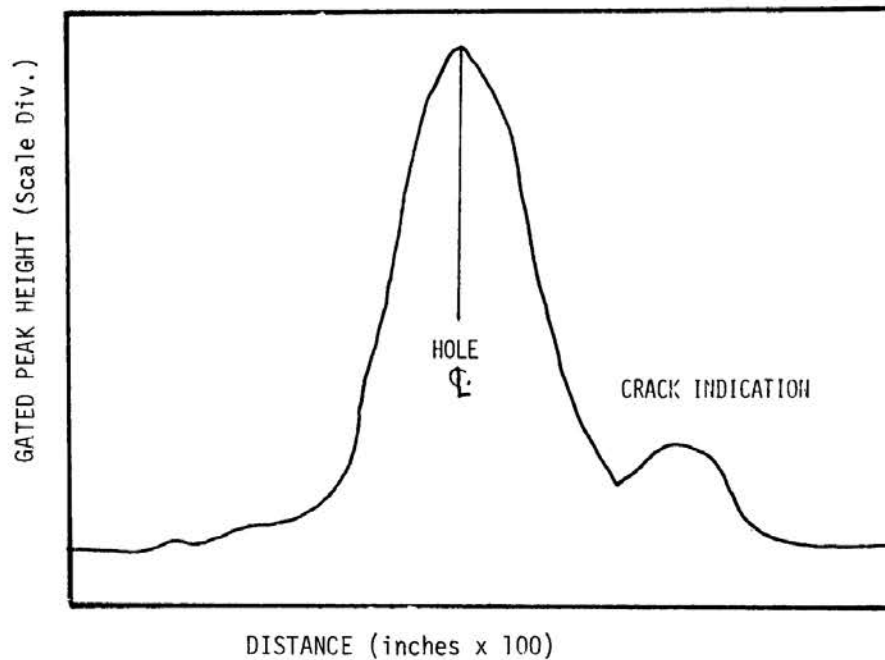


Fig. 2. Typical ultrasonic shear wave indicia of hole with crack (0.5 dia.)

mitter/receiver. The particular signal recorded is that found within a gated position selected previously by considering the reflections from a known defective sample. As the transducer scans across the specimen, the reflected energy slowly rises from zero to a maximum and decreases. This scan is of a 0.5" diameter straight shank drilled and reamed hole. If there is a crack growing out of the drilled hole, the ultrasonic waves are perturbed by the additional reflections associated with the crack as well as the original reflections associated with the straight shank hole. Hence, the indicia associated with the ultrasonic scan of the hole plus the crack will look typically as shown in Fig. 2. Here the crack is located perpendicular to the scan direction.<sup>21</sup> Thus, the indicia gives information regarding the presence of the crack in the vicinity of the drilled hole.

The technique used by Gurvich and Yermelov measures the width of the indicia at a predetermined level and the skewness of the curves. Consequently, the characteristics of the scattering does not precisely determine the shape of the flaw, but it becomes important to determine the known scattering from ideal reflectors such as spheres, spheroids and discs, etc.

#### Experimental Program

The purpose of the experimental program was to develop a series of indicia for scattering from known, well characterized defects imbedded in the interior of right circular cylinders. The specimens were prepared by Rockwell International as part of the ARPA/AFML interdisciplinary program on flaw characterization. The procedures and techniques used to measure and characterize the defect type, size and base material have been described elsewhere.<sup>22</sup>

Ultrasonic indicia were run for all specimens examined, as well as for 1, 2, 3, 4, and 5 sixtyfourths flat and conical bottom holes prepared in our laboratory from 6061 Aluminum. In all cases a 3/8 dia. 5 MH Automation SFZ ultrasonic transducer was used. The ultrasonic system was a Sperry UM 715 with a Transigate H gate system. All scans were produced on a specially designed fixture. In this fixture the position can be recorded directly using a 10 inch slide wire position transducer and scanning speeds controlled with a variable speed screw drive mechanism for one axis. The other axis was indexed using a micrometer drive that is manually operated. The amplified DC signal from the Transigate was fed into the Y axis of an X-Y recorder while the position signal was used as the X axis. At least two series were run for each specimen examined; 1) a low sensitivity position scan to obtain the general configuration for the indicia and 2) a high sensitivity position scan to obtain suitable indicia for subsequent digitizing for signal analysis.

The scanning unit also had provisions for micrometer movements in x, y and z directions. Typically, the z position was set so that sufficient oil contact was maintained during a scan, and subsequently unchanged. A typical series of scans would be made by first indexing the x-y positions to obtain the supposedly largest reflected signal from the defect within the pre-selected gated position. Scans were then produced with the screw drive unit automatically moving the transducer in the y direction. When a trace was completed, hand step scanning was used in the x direction. Thus, a series

of indicia could be developed from a trace that indicated no defect within the ultrasonic gate, pass through a maximum and then decrease as  $y$  varied, for each position. Typical indicia obtained are shown in Fig. 3 and 4, for 0.025 inch  $x$  position changes.

Since both indicia were made using the same sensitivity for the  $y$  motion, and an equal 0.025 step position for the  $x$  position of the transducer, the difference in the indicia can be attributed only to the shape of the flaw. It thus appears that one specimen is not symmetrical about the vertical axis, since the number of indicia obtained is considerably smaller than that obtained on the second specimen. The apparent area of the defects are roughly the same, since the maximum peak heights of the (maximum indicia) are roughly the same. Hence, one must conclude that one defect shape is elliptical in nature and is elongated along the transverse scan axis. If both defects were circular, the scans would be roughly the same, and there would be approximately the same number of  $x$  traverses.

### Experimental Results

The simplest method of describing the indicia is to consider the amplitude-distance pulse to be the equivalent of an amplitude-time pulse.<sup>23</sup> If this mechanical shock or impulse is applied to a linear system, and the response of the system to a unit impulse is known, the response of the system to the pulse in question can be estimated by the following:

$$X(t) = \int_{-\infty}^{+\infty} f(\tau) h(t-\tau) d\tau \quad (1)$$

where  $X(t)$  is the response

$f(t)$  is the forcing function

$h(t-\tau)$  the unit impulse response of the system

$t$  a dummy time variable

The integral involves the convolution of two complicated functions and the exact solution usually poses formidable difficulties. The analysis can be simplified by applying the Fourier transform to the phenomena and describing the transformation in the frequency domain. It should be emphasized that with the Fourier transform analysis of the indicia, the impulse is space-like instead of time-like as with the more commonly accepted pulses.

The Fourier transform is defined as

$$A(f) = \int_{-\infty}^{+\infty} f(t) e^{-i2\pi ft} dt \quad (2)$$

with the additional requirement that  $f(t)$  is finite. When  $f(t)$  is a shock or indicia the latter requirement is automatically satisfied since at  $t = 0$ , and  $t-f$ ,  $f(t) = 0$ .

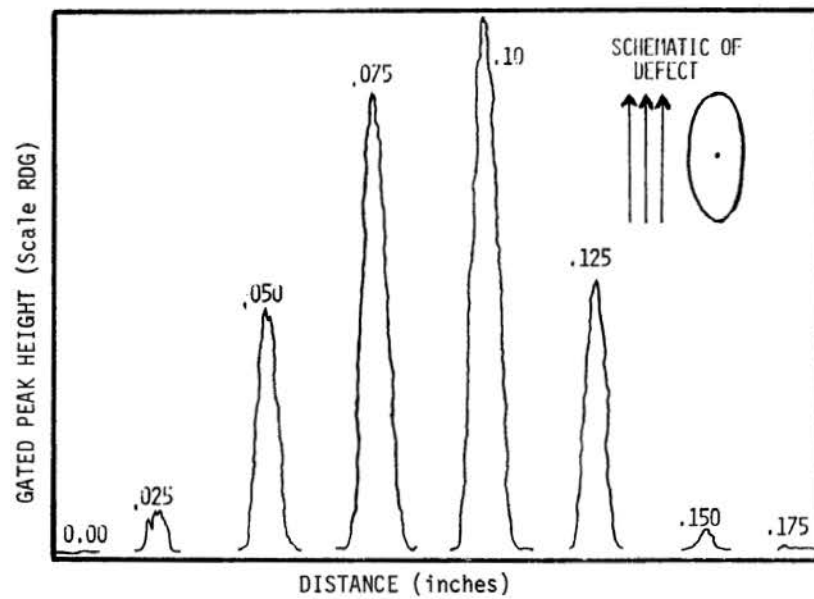


Fig. 3. Typical ultrasonic normal wave indicia of imbedded defect, each scan is step index of 0.025 in.

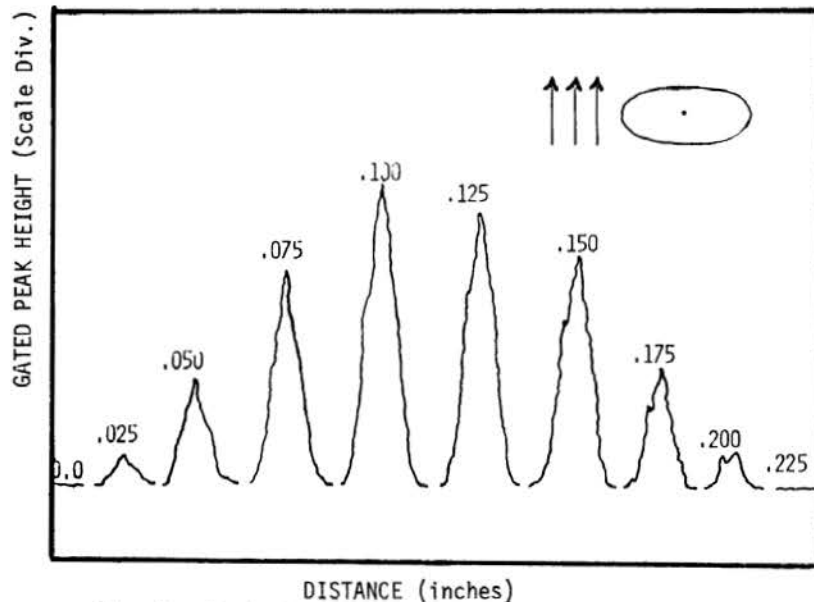


Fig. 4. Typical ultrasonic normal wave indicia of imbedded defect, each scan is step index of 0.025 in.

If the driving function is given by a short duration square pulse of duration  $T$ , and amplitude  $A$ , shown in Fig. 5, the Fourier spectrum of the rectangular pulse is given by:

$$A(f) = AT \frac{\sin \pi ft}{\pi ft} \quad (3)$$

This is shown in Fig. 6. Thus, it appears that driving functions that are Dirac in nature, transform into a series of loops whose frequency between nodes (zeros) is inversely proportional to the width of the pulse  $T$ . Similar results can be obtained for sinusoidal driving pulses and triangular pulses.<sup>23</sup>

Since the observed indicia are all pulse-like in nature, an analysis was made to determine the Fourier spectrum of the indicia. A typical Fourier spectrum of an indicia is shown in Fig. 7. For some indicia it was found that the nodes did not necessarily pass through zero, but had minimum which could be associated with the width of the pulse. This means that in contrast to the Dirac or Square pulse which is missing energy at certain frequencies, these pulses contained energy in these positions.

A plot could then be made of the "order of the node" vs. the frequency at which the node passed through zero, or through a minimum. For most of the specimens examined this resulted in a straight line, indicating that the general shape of the indicia was that of a space-like pulse, whose shape could be described in terms of some idealized width related to the equivalent width that the ultrasonic probe believes the defect to be.

Since the actual width of the defect is known and the number of passes needed in the step scanning system is also known, the width of the largest peak indicia can be taken to correspond to the transducer scanning the defect at its widest point. Hence, a graph of the slope of the node order-frequency plot could be determined as a function of the known maximum width of the series of defects. This is shown in Fig. 8. Using a least squares fit, a straight line has been drawn through the experimental points.

The analysis of an unknown defect would then proceed as follows:  
 1) the maximum indicia height pulse would be transformed into frequency space. The position of the nodes would be determined, and the slope of the order-frequency plot determined for this unknown. Entering Fig. 8 the width of the unknown could then be determined. If a series of scans are made for an unknown, and the position of the Y axis known, then the value of the ultrasonic indication of the width of the specimen could be determined at each scan position. The first and last indicia are essentially straight lines, of Fig. 3 and 4 (when the probe field no longer interacts with the defect). Hence, the maximum of the indicia for each scan in the step variable  $X$  positions of the scan unit could also be considered as an indicia of the scan in the  $X$  direction. This is reasonable for if the scan were made in a direction  $90^\circ$  to the original scan, the value of the ultrasonic width of the defect could be determined in a more straight forward manner by examining Fig. 8.



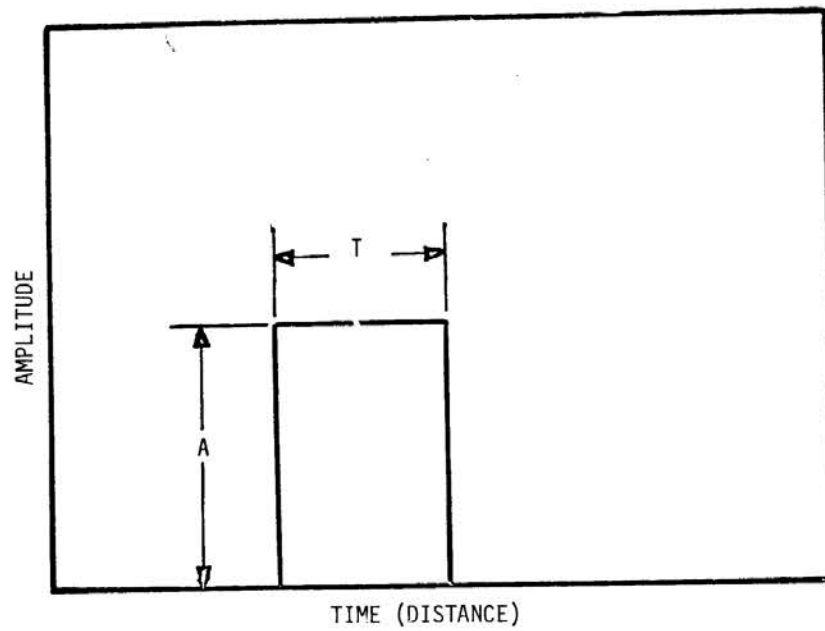


Fig. 5. Square pulse for driving function for impulse analysis

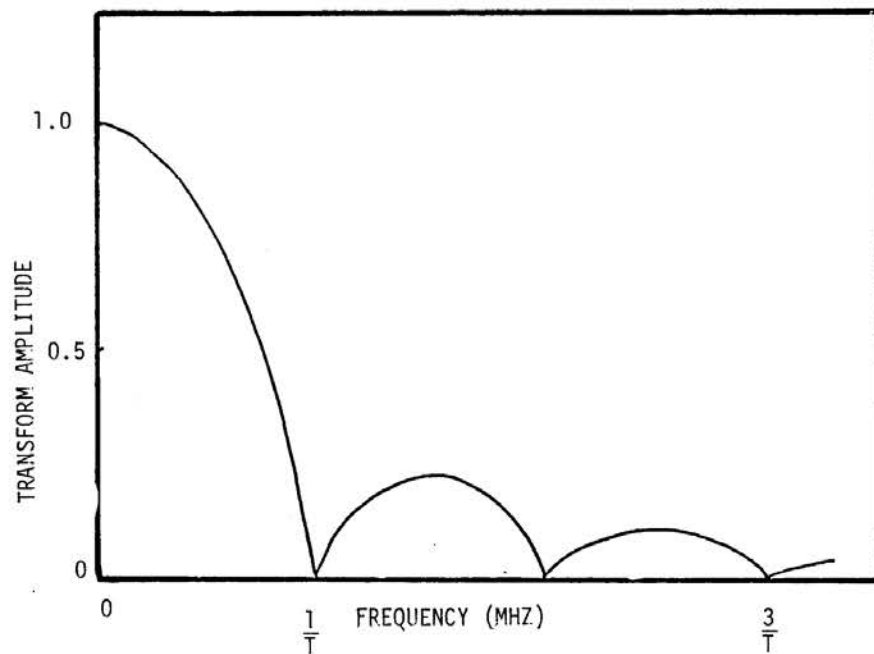


Fig. 6. Fourier spectra for pulse shown in Fig. 5.

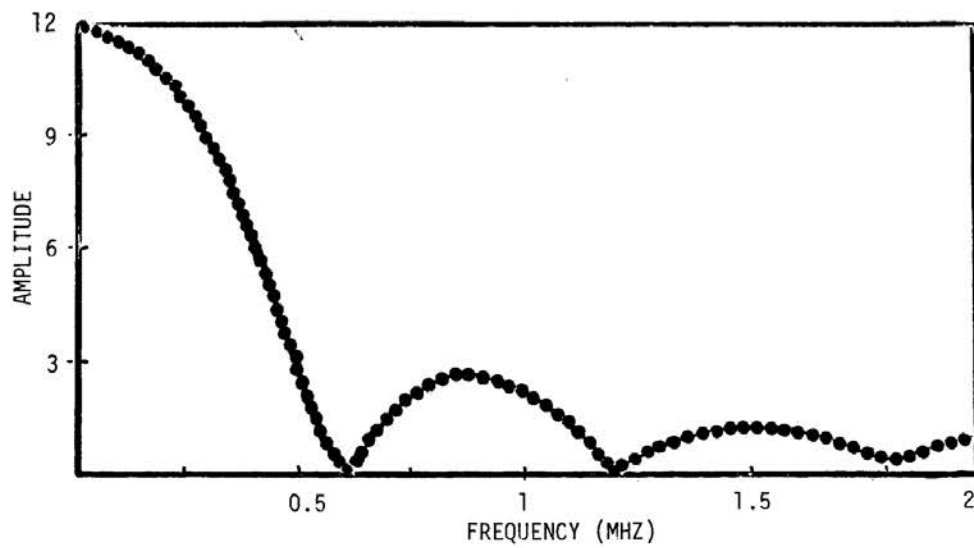


Fig. 7. Typical power spectra of defect indicia

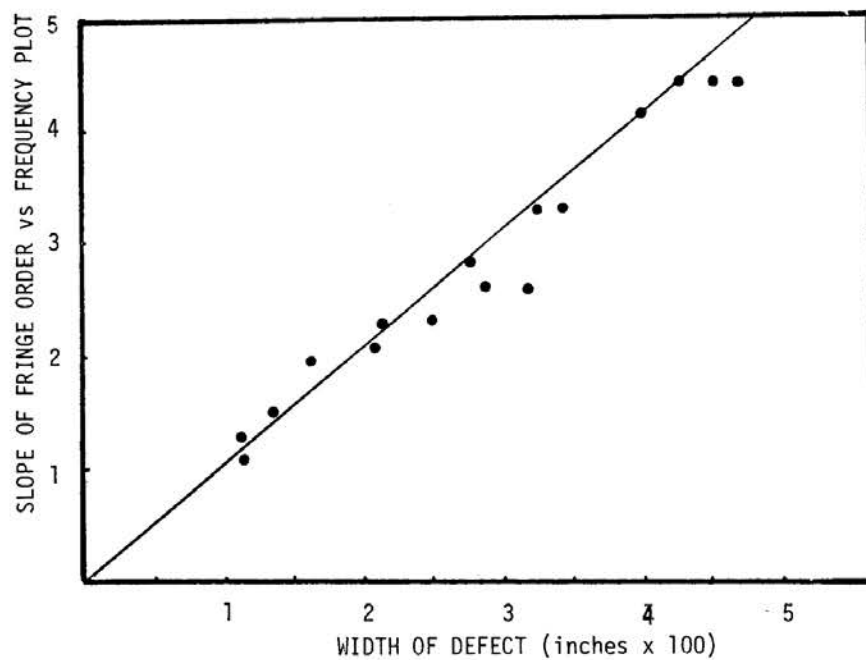


Fig. 8. Slope of fringe order vs frequency plot (m) vs actual defect width

Following this reasoning, one can reconstruct the shape of the defect from the analysis of the indicia. The reconstruction of typical spherical defect, specimens N, O and P are shown in Fig. 9. The major problem with these results appear to be that the inherent scatter in the slope curve, Fig. 8 results in uncertainties in the ultrasonic width and hence, the exact shape of the defect. It would be difficult to determine if the defect were truly ellipsoidal in shape or circular.

This method of measuring the shape of the defect depends strongly on the shape of the pattern of the lobes of the pressure pattern generated by the transducer. It has been observed that if the transducer is rotated slightly, the pressure pattern of the transducer changes and can influence the shape of the indicia; hence, the analysis of the size of the defect. The process must be repeated for each transducer.

A more direct method of determining the shape of the defect can be made following Gurvich and Shchukin and Gurvich and Yermolov.<sup>19,20</sup> These authors give an impression for the shape of the indicia when the probe sonic axis and the scattering axis of the defect (assumed to be spherical or disc like) are aligned during the scan. The standardized function for the envelope sequence of echo signals or the shape of the maximum indicia is given by:

$$F(x) = \phi_0 \left( \arctg \frac{x_i}{H} \right) \cos^2 \left[ \frac{\pi}{5\phi_0} \left( \arctg \left\{ \frac{x_i}{H} \right\} - \alpha_0 \right) \right] \times \frac{\left( x_i^2 + H^2 \right)^{-n/2} \exp \left[ -2\delta \left( x_i^2 + H^2 \right)^{1/2} \right]}{\phi_0 \left( \arctg \frac{x_i}{H} \right) \cos^2 \left[ \frac{\pi}{5\phi_0} \left( \arctg \frac{x_i}{H} - \alpha_0 \right) \right] \left( x_i^2 + H^2 \right)^{-n/2} \exp \left[ -2\delta \left( x_i^2 + H^2 \right)^{1/2} \right]} \quad (4)$$

Where  $f(x)$  is the indicia function

$x_i$  = position of the transducer at the maximum echo signal

$H$  = the depth of the defect

$\phi_0$  = scattering coefficient of defect

$\alpha_0$  = angle relating the major pressure pattern angularity

$\delta$  = attenuation coefficient

$n$  = 2-spheres, 1-disc

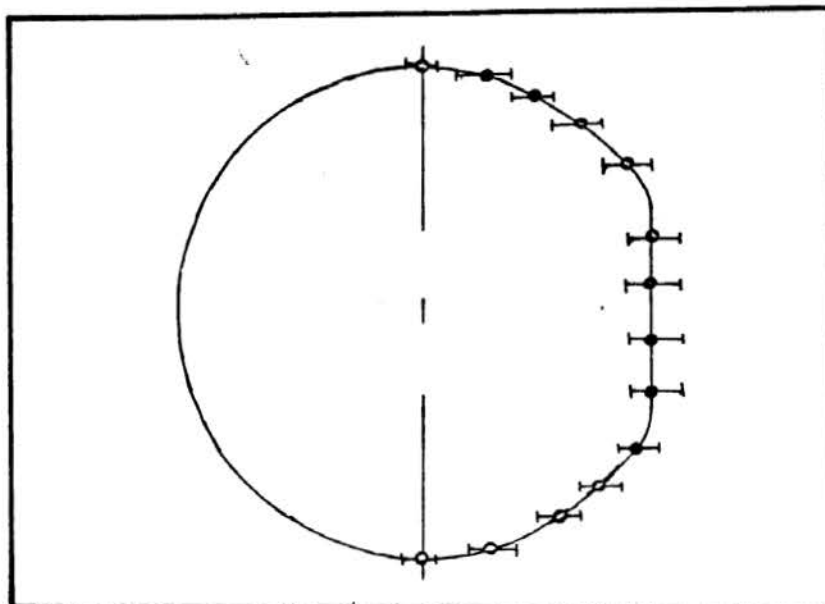


Fig. 9. Plot of ultrasonic indicia defect shape (RH. Side) vs actual defect shape (LH side).

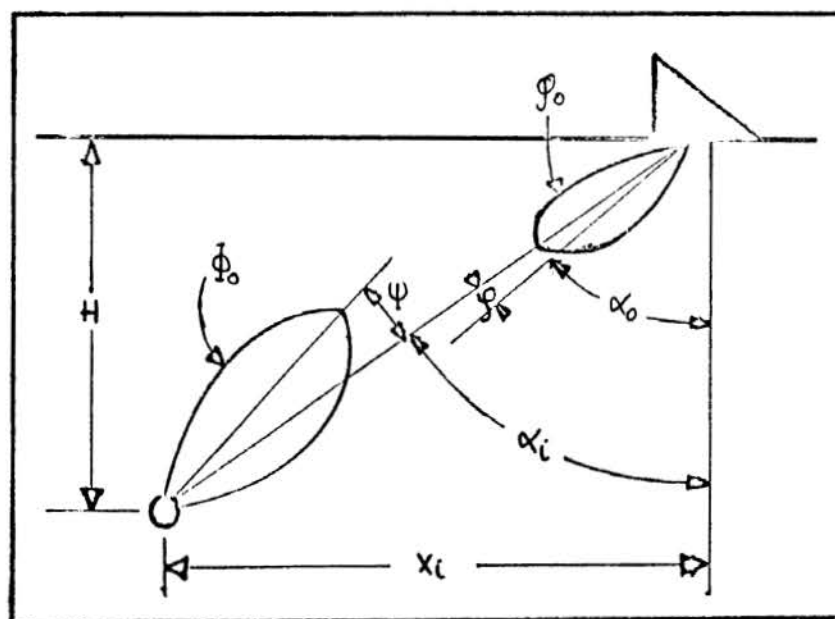


Fig. 10. Schematic for calculating scattering indicatrix of a reflector.

The experimental configuration for this system is shown in Fig. 10. Since the shape is normalized, i.e. the scattering factor for the actual defect configuration divide out, one is primarily interested in the changes of shape that occur with changes in the beam width of the transducer, i.e. change in the  $\phi_0$ . Computations of the standardized indicia for various values of  $\phi_0$  are given in Fig. 11. It can be seen that the analysis predicts secondary peaks, and indicate that for certain conditions the ultrasonic signals should drop and rise again with further motion of the transducer. This has been observed with 45° shear wave transducers<sup>21</sup> and is due to the formation of multiple reflections from the defect with the gated position as the transducer moves over a large distance. However, for this analysis we are interested primarily in the shape of the primary peak. By a suitable choice of  $\phi_0$ , the maximum indicia can be made to agree nicely with the predicted curves, as seen in Fig. 12.

It should be pointed out that in this analysis, the shape of the ultrasonic pressure pattern from the transducer given by the parameter  $\phi_0$  is not known apriori, and that here too, a best fit must be made with the data using some known flaw as a standard. The pressure pattern of the transducer may also alter depending upon the rotation of the transducer, and must be determined for each transducer. However, once the pressure pattern of the transducer is well established analysis of the shape and indicia is relatively straight forward.

### Conclusions

The ability of the ultrasonic indicia to characterize the shape and size of imbedded defects has been developed and examined. The results of an experimental program to characterize these defects has shown the following:

1. The shape of the indicium gives an indication of the shape of the defect and can distinguish between elongated defects and spherical defects.
2. By considering the indicia to be pulse-like instead of space-like, a frequency spectra can be determined by making the appropriate Fourier transform. The position of the nodes of the spectra can be used to determine the size of the imbedded defect, and to determine the size of the imbedded defect, and to approximate the shape of the defect.
3. The shape of the maximum indicia can be analyzed using Gurvich and Yermelov's analysis and can be made to fit well with the established curves if the shape of the pressure pattern from the transducer is used as the independent variable.
4. The characterization of size and shape of small defects by either the Fourier transform of the indicia or by the Gurvich and Yermelov analysis is dependent upon the orientation of the transducer and the pressure pattern of the transducer, and rotation of the transducer can lead to significant errors.

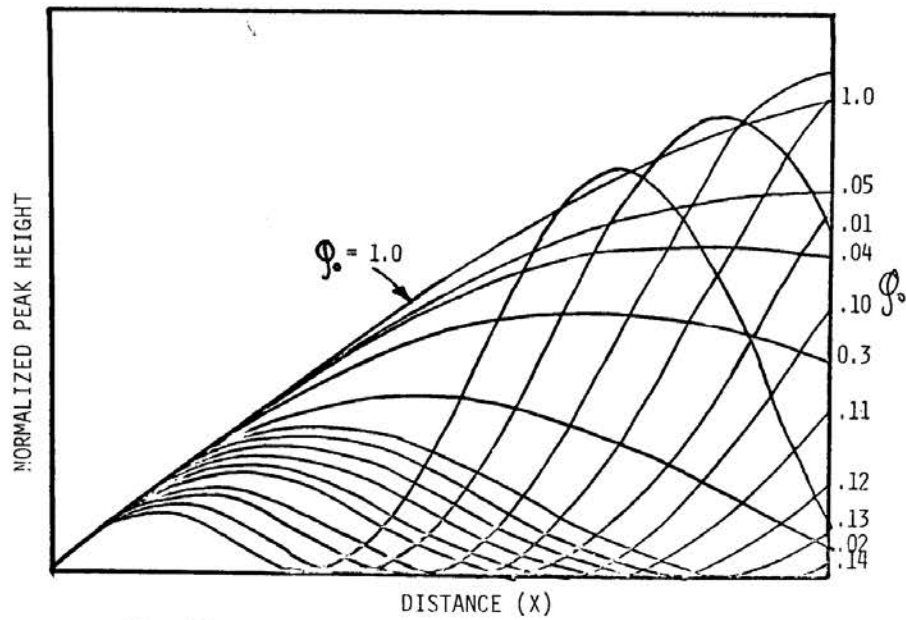


Fig. 11. Effect of probe pressure pattern angle on indicia of sphere

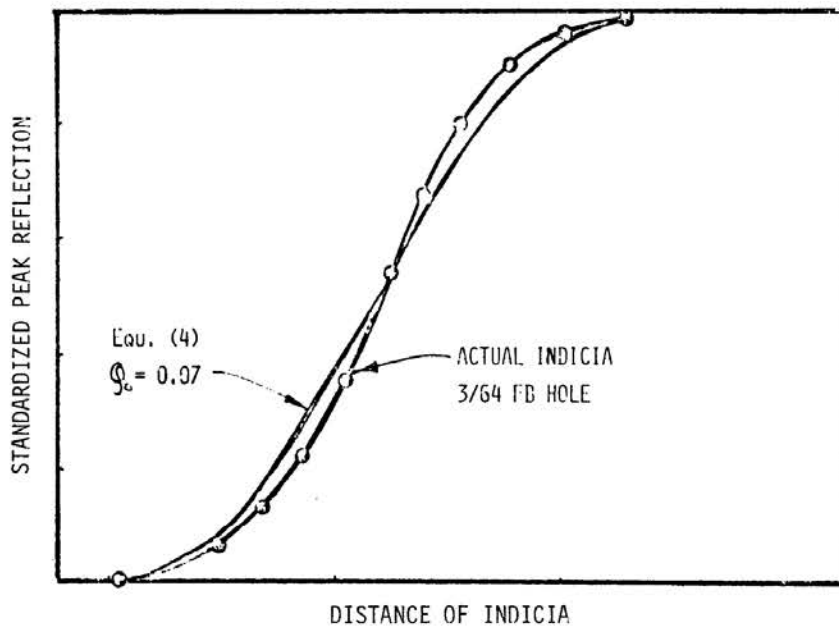


Fig. 12. Comparison of equation 4  $Q = 0.07$  with actual indicia of 3/64 FB hole.

## References

1. Bishop, C. R., Nondestructive Evaluation of Fatigue Cracks, SH 73-SH0219, Space Div., Rockwell International Sept., 73.
2. Rummel, W. D. Todd, P. H., Frecska, S. P., Rathke, R. A., The Detection of Fatigue Cracks by Nondestructive Testing Methods, NASA CR 2369, Feb. 1974.
3. Packman, P. F., Pearson, H. S., Owens, J. S., Marchese, G. B., Definition of Fatigue Cracks by NDT, Journal of Materials 4 (1963) 3.
4. Pettit, D. E., Hoeppe, D. W., NAS 9-11722 (1972).
5. Sattler, F. S., Nondestructive Flaw Definition Techniques for Critical Defect Determination, NASA CR 72602 (Jan. 1970).
6. Thomas, E. F., Kloster, W. E., F-111 NDT Human Factors Reliability Program ASM Preprint (1971).
7. Corbly, D. M., Packman, P. F., Pearson, H. S., Materials Evaluation Vol. 28 (1970) p. 103.
8. Sessler, J. G., Weiss, V. W., ARPA Final Report, 8010 Oct. (1970) "Improvement in Crack Detection by Ultrasonic Pulse Echo with Low Frequency Excitation".
9. Packman, P. F., "Influence of Topography in Flaw Detection by Ultrasonics", Presented International Conference NDT, Warsaw 1973.
10. Klima, S. J., Freche, J. C., Ultrasonic Detection Measurement of Fatigue Cracks in Notched Specimens, NASA Tn D-4782 (1969).
11. ANON: Ultrasonics; Vol. I Basic Principles. NASA CR-61209 (1967) Vol. III Applications NASA CR-6141, Bastien, P., Difficulties in the Ultrasonic Evaluation of Defect Size, Nondestructive Testing, Feb. (1968) p. 147.
12. Makara, A. M., Tsechal, V. A., Zhovnitskii I. P., Avtomatich-eskaya Svorka, Vol. 5 (1961) p.3.
13. Tietz, H. D., "Contribution to the Flaw Detection in the Ultrasonic Pulse Echo Technique by Investigation of Model Like Flaws," 7th International Conference in NDT, Warsaw June 1973.
14. Opel, P., Ivens, G., "Determination of Flaw Size with Ultrasonics in Forgings", Rept. 1320, Materials Committee Union of German Iron Workers, Sept. 1961, Reprinted by Krautkramer Ultrasonics Reprint 906.
15. Krautkramer, J., Krantkramer, H. , Ultrasonic Testing of Materials, Springer-Verlag, N.Y. (1969).

16. Giacombo, G. D., Crisa, J. R., Goldspiel, S., Materials Evaluation (1971) p. 189.
17. Whaley, H. L., Cook, K. V., "Ultrasonic Frequency Analysis", Materials Evaluation 28 (1970) 61.
18. Redwood, M., "A Study of Waveforms in the Generation and Detection of Short Ultrasonic Pulses", Applied Materials Research April (1963).
19. Gurvich, A. K., Shchukin, V. A., Defektoskopia, Nov., Dec. (1970) p. 685.
20. Gurvich, A. K., Yermelov, I. N., Ultrasonics Flaw Detection in Welded Joints, Izdvo Tekhinka, Kiev (1972).
21. Packman, P. F., Impulse Analysis of Ultrasonic Indicia, Proceedings of Interdisciplinary Workshop for Quantitative Flaw Definition, AFML TR-74-238, June 1974.
22. Proceedings of Interdisciplinary Workshop for Quantitative Flaw Definition, July 1975, to be published.
23. Broch, J. T., Olesen, H. P., "On the Frequency Analysis of Mechanical Shocks and Single Impulses", Presented 78th Meeting of Acoustical Society of America, Nov. 1969. B & K Technical Review #3 (197).



## DISCUSSION

DR. ONO (UCLA): It seems to me that the convolution you are taking is a special one and you would also have to consider the shape of the transducer's output.

PROF. PACKMAN: Yes. That's what I'm talking about.

DR. ONO: And you hardly mentioned that it's a Dirac  $\delta$ -function pulse as an input, and this doesn't seem to match with what you normally use.

PROF. PACKMAN: Now, I think I went too fast. I was talking about two different things. When I do the Laplace transform, which is the go/no go flaw identification out of a hole, I do an impulse analysis, which is the Laplace transform. In that particular case, the input function happens to be a Dirac  $\delta$ -function only because of the fact that the Dirac transforms to unity. When I do the characterization by the indicia off the Rockwell specimens, it's all in the Fourier transforms. There are no impulses. In other words, there is no--

DR. ONO: Weren't those Fourier transforms at that point? You just used the deconvolution, right?

PROF. PACKMAN: Right. There is no input function. In other words, the Dirac  $\delta$ -function is not an input function in the Fourier transform. It's just a frequency spectrum.

DR. ONO: That's the point where I'm sort of confused. You are merely taking the special convolution.

PROF. PACKMAN: Right.

DR. ONO: So that you really need the special function of the input transducer. Then you are trying to deconvolute that response function.

PROF. PACKMAN: Yes.

DR. ONO: What is that shape when you are taking that deconvolution?

PROF. PACKMAN: It's the shape of the scan. In other words, it looks something like this--it would look something like this, where this would be amplitude versus position; and this is what I made a Fourier transform of.

DR. ONO: Yes. But in order to get that shape, the final shape you deconvolute?

PROF. PACKMAN: I deconvolute.

DR. ONO: You also need the shape of the transducer's response?

PROF. PACKMAN: No. All I'd do is I'd get a shape that would look like this and I take these nodal positions, and this is related to some measure of the ultrasonic measure of the defect's width.

PROF. J. A. KRUMHANSL (Cornell University): Very briefly, a clarification. Ermolov's analysis is for scalar wave acoustics, right?

PROF. PACKMAN: Yes.

PROF. KRUMHANSL: Well, I think the philosophy of what you are doing is interesting, but I think once you realize, I think it's been brought out before, that going too quantitatively into the interpretation of the analysis of these functions is a little bit of game playing for now. I wish we could provide you with something more up to date, but that's hopefully coming.

PROF. PACKMAN: Yes. I agree. I said that I think, you know, we're kidding ourselves in thinking that it's giving me some original information out of it, because it's transducer dependent. It isn't an absolute, I'm using the transducer to make my measurements and then I'm using my transducer to deconvolute to tell me what the defect looked like, which is really the kind of thing I'm doing.

PROF. KRUMHANSL: Being guided by experience is perfectly valid in adapting analogies from geometric objects to this problem.

PROF. PACKMAN: Right. That's exactly what's going on.

DR. WOLFRAM (University of Missouri): We have time for one more short question.

MR. ABALOS (Rockwell, Space Division): When you have your Fourier signal of the unknown, I think you mentioned you attempted to trace your steps back and determine what the unknown looked like. Did you try any digital frequency techniques or any sharpening up of your Fourier signal to attempt to get a better picture of the unknown?

PROF. PACKMAN: No. This is something I learned Thursday in San Francisco. Those extra indicia are not nice smooth indicia like this. Some of them appear to have things like this associated with them, and these things are associated with the fact that you've got a wave here, and you've got another wave here. This thing appears to be associated with the fact that I'm not gating close enough. In other words, I'm getting two signals--two waves are coming back, and as I rotate across, the relative magnitude of those two waves changes.